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APPARATUS AND METHOD FOR THERMO-
ELECTRIC COOLING

BACKGROUND OF THE INVENTION

[0001] This invention relates generally to medical devices. In particular, this invention relates to X-ray detectors with cooling capabilities.

[0002] Imaging electronics found inside X-ray detectors generate thermal energy that must be removed in order to maintain a temperature within an operating range at an X-ray panel. Further, the X-ray panel must be kept on during some procedures that require continuous real-time imaging. The constant operation of the X-ray panel results in an equally continuous requirement for removal of the thermal energy.

[0003] Approaches for the removal of thermal energy are further constrained by the environment in which X-ray detectors operate. X-ray detectors are often constrained environmentally and dimensionally. Environmentally, the X-ray detectors are often used in sterile environments, such as an operating room and enclosed in a plastic sterile bag or other sealed enclosure when in operation. The sterile environment also affects the ability to use forced air-cooling in the X-ray detector. Further, the plastic sterile bag or other enclosures often insulates the X-ray detector and results in an increase of thermal energy. Dimensionally, the X-ray detector is part of an X-ray unit that often has to be compact and mobile. Such size requirements require the X-ray detectors to be designed with more constrained airflow and less efficient convection cooling.

[0004] In the past, thermal energy transfer in X-ray detectors has been accomplished by a temperature conditioner that circulates liquid coolant through a cold plate attached to the X-ray detector. However, this approach increases the size of the X-ray unit and creates additional issues of corrosion and material incompatibility. Further, the liquids used in cooling systems are often regulated by legal agencies such as the Environmental Protection Agency (EPA), thereby limiting their usefulness in some instances.

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[0005] Therefore, a need exists for cooling X-ray detectors within a sterile environment and constrained area.

BRIEF DESCRIPTION OF THE INVENTION

[0006] Methods and apparatus consistent with the present invention provide temperature regulation for an X-ray detector even when constrained by a sterile environment and within a confined space. The X-ray detector solution is implemented using solid-state devices. As a result, a less expensive temperature regulator allows thermal control over cooling and heating of the X-ray panel within the X-ray detector in order to maintain the temperature within an acceptable thermal range.

[0007] In one implementation, two thermally conductive surfaces form an upper and lower surface above and below a number of thermo-electronic devices. The thermo-electronic devices create a thermal gradient when electrical power is applied. When one of the thermally conductive surfaces is connected to an X-ray detector, the other acts as a heat dissipater. Thus, thermal control is achieved by a controller that monitors the temperature in the X-ray detector and adjust the current and voltage polarity in the thermo-electronic devices

[0008] Other apparatus, methods, features and advantages of the present invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the present invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. In the figures, like reference numerals designate corresponding parts throughout the different views.

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[0010] Figure 1 is a cross sectional view of a thermo-electric temperature device attached to a body to be cooled.

[0011] Figure 2 is a diagram of a thermo-electric temperature regulator incorporating thermo-electric devices of figure 1 attached to an X-ray detector.

[0012] Figure 3 illustrates a block diagram of the thermo-electric temperature regulator of figure 2.

[0013] Figure 4 is a block diagram of a circuit with the thermo-electric temperature regulator of figure 2.

[0014] Figure 5 is a flowchart of the process that maintains the temperature of the X-ray detector of figure 2.

DETAILED DESCRIPTION OF THE INVENTION

The invention may be better understood with reference to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principals of the invention. Moreover, in the figures, like reference numerals designate corresponding parts throughout the different views.

[0015] While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.

[0016] In figure 1, a cross sectional view of a thermo-electric temperature device 100 attached to a body 102 that needs cooling is shown. The thermo-electric temperature device 100 includes an electrical insulator 104, a conductive element 106, Bismuth Telluride semiconductor substrate material area doped with a n-type semiconductor material 108 and another area doped with p-type semiconductor material 110. Each of the doped semiconductor material areas 110 and 108 are in contact with an associated electrode 112 and 114. The electrodes 112 and

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114 rest on another electrical insulator 116 that is in contact with a heat sink 118. A battery 120 provides current to the thermo-electric temperature device 100.

[0017] When current is applied from the battery 120 to the thermo-electric temperature device 100, a path is created from the battery 120 through the electrode 114, the p-type doped semiconductor material 110, the conductive element 106, the n-type doped semiconductor material 108, electrode 112, and back to the battery 120. A hot junction and cold junction are created by the electrical current flowing through the thermo-electric temperature device 100.

[0018] The cold junction occurs at the conductive element 106 and cools the body 102. Heat is pumped to the hot junction, the other conductive element 116, from the cold junction at a rate proportional to the current passing through the electrodes 112 and 114. More precisely, the thermal energy at the thermal conductor 106 is absorbed by electrons as they pass from the low energy level in the p-type doped semiconductor material 110, to a higher energy level in the n-type semiconductor material 108. Upon reversing the current's direction through the electrodes 112 and 114, the hot junction and cold junctions reverse. Therefore, the thermo-electric device 100 may operate in one of two modes (cooling or heating) depending on the direction of the supplied current. The thermo-electric device 100 is shown connected to a battery supplying the current. In alternate embodiments, other type of current generating devices may be used such as a generator, alternator, and solar cells.

[0019] Turning to figure 2, that figure shows a thermo-electric temperature regulator 200 attached to an X-ray panel 208 of an X-ray detector. Current is supplied to the thermo-electric regulator 200 from the positive voltage contact 201 and negative voltage contacts 202. The thermo-electric regulator 200 is in contact with a cold plate 204 and heat sink 206. The cold plate 204 is made from a material that is thermally conductive, such as aluminum. The space between the cold plate 204 and the heat sink 206 is filled with thermal insulation 210 that serves as a thermal barrier between the cold plate 204 and the heat sink 206. A heat dissipating plate 212 may be placed in contact with the X-ray panel 208 in order to conduct

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thermal energy away from the X-ray panel 208. The heat dissipating plate 212 may be made out of the same material as cold plate 204. In an alternate embodiment, the heat dissipating plate 212 may be made from thermal conducting ceramic.

[0020] The heat pipe 214 is in thermal contact with the cold plate 204, while the heat dissipating plate 212 is in thermal contact with the heat pipe 216. The heat pipes 214 and 216 are similarly in contact with each other. Thermal energy generated by the X-ray panel 208 within the X-ray detector is dissipated by the heat dissipating plate 212 and transferred to the cold plate 204 by the heat pipes 214 and 216. The cold plate 204 and heat pipe 216 are thermally isolated from contacting the other electronics 222 by thermal insulation 218 and 220 in order to transfer thermal energy from the X-ray panel 208 through the heat pipes and not through the other electronics 222. The thermal insulation 210, 218, and 220 may be made from an epoxy based insulation material, for example. The heat pipes 214 and 216 may be made out of thermal conducting material identical to the cold plate 204. In other embodiments, the heat pipes may also be made from thermal conducting ceramic material.

[0021] The thermo-electric device 100 allows thermal energy to be transferred from the X-ray panel 208 within the X-ray detector without placing possible harmful and corrosive liquids in the X-ray unit. The thermo-electric device 100 also allows a compact X-ray unit to be designed and deployed without increasing risk of infection to patients. Further, the thermo-electric device may be attached directly to the X-ray panel 208 and adjusted to maintain the temperature in the X-ray detector within a predetermined operating range.

[0022] A temperature conditioner 3 to 15 meters away from the X-ray detector may be used in conjunction with the thermo-electric device 100 in order to achieve the desired goal of temperature control of the X-ray detector. Examples of a temperature conditioner include a chiller or a heat exchanger. The thermal connection between the X-ray panel 208 in the X-ray detector and the thermo-electrical device may be accomplished with a heat pipe or any other highly conductive material. Further, the X-ray panel may be substantially isolated from the rest of the

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cooling system allowing additional control of the temperature at the X-ray panel 208 within the X-ray detector.

[0023] In figure 3, a block diagram of the thermo-electric temperature regulator 200 of figure 2 is shown. A top plate or heat sink 206 covers the thermo-electric devices 100. The thermo-electric devices 100 are enclosed by an isolation layer or thermal insulation layer 210 that is below the heat sink 206. Although Figure 3 shows four thermo-electric devices 100 arranged to form the temperature regulator 200, it is noted that additional or fewer thermo-electric devices 100 may be used in any particular regulator design, according to pre-defined heating or cooling needs. The thermal insulation layer 210 thermally isolates the heat sink 206 from the cold plate 204. Some examples of material that may be used in the isolation layer include ceramics and silicon material. The positive voltage contact 201 and negative voltage contacts 202 provide paths for current to flow to the thermo-electric devices 100. The isolation layer 210 along with thermo-electric devices 100 are contact with both the heat sink 206 and the cold plate 204.

[0024] Turning to figure 4, a block diagram 400 of support circuitry for the thermo-electric temperature regulator 200 of figure 2 is shown. A controller 402 is connected to a temperature sensor 404, a temperature regulator 200 and a power supply 408. The power supply 408 is connected to the controller 402 and temperature regulator 200. The controller 402 may be a microprocessor or micro-controller programmed to adjust the current supplied by the power supply 408 to the temperature regulator 200. In other embodiments, the controller 402 may be an application specific integrated circuit (ASIC), discrete logic functioning as a controller, analog devices functioning as a controller, or a combination of the above configured to function as a controller.

[0025] The controller 402 may reverse the voltage generated by the power supply 408 and received by the thermo-electric device 406. In one embodiment, the controller 402 activates a switch 410, such as a relay, to reverse the voltage. In an alternate embodiment, a solid-state device may be used to switch the voltage and switch the thermo-electric device from a cooling mode to a heating mode.

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The controller 402 may be located within the X-ray detector or may be located external to the X-ray detector.

[0026] In figure 5, a flowchart 500 shows the process that maintains the temperature of the X-ray detector in figure 2. The process starts (Step 502) with the controller 402 being initialized upon power being applied to the X-ray detector (Step 504). The temperature sensor 404 measures the temperature within the X-ray detector (Step 506). The measured temperature is reported to the controller 402 where the controller 402 determines if the temperature of the X-ray detector is within a predetermined operating range (Step 508). If the temperature is within the operating range, then the temperature of the X-ray detector is again measured by the temperature sensor 404 (Step 506). If the temperature is not within a predetermined operating range, then the controller 402 determines whether heating or cooling is desired (Step 510).

[0027] If heating is desired, then the voltage is adjusted by reversing the voltage received at the positive and negative inputs of the thermo-electric device 406 (Step 512). The default configuration is with the voltage polarity configured so the thermo-electric device 406 cools the X-ray detector. The amount of cooling is controlled by adjusting the current through the thermo-electric device 406 (Step 514). More current yields increased cooling. If cooling is desired and the voltage is in the default configuration, then the current is adjusted to either decrease or increase cooling (514). If cooling is required and the voltage is configured for heating, then the voltage is reversed. In an alternate embodiment, a fix current is supplied to the thermo-electric device 406.

[0028] The process is shown as stopping in figure 5 (Step 516). In practice, the process is continuously repeated by returning to step 506. In another embodiment, the process is repeated a predetermined intervals, such as every 30 seconds. In other embodiments, the process may be repeated upon a temperature threshold being detected.

[0029] The foregoing description of an implementation of the invention has been presented for purposes of illustration and description. It is not

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exhaustive and does not limit the invention to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practicing of the invention. For example, the described implementation includes software but the present invention may be implemented as a combination of hardware and software or in hardware alone. Note also that the implementation may vary between systems. The invention may be implemented with both object-oriented and non-object-oriented programming systems. The claims and their equivalents define the scope of the invention.